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Nuclear Instruments and Methods in Physics Research A 00 (2000) 000–000

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

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Making the most of aging scintillator☆

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Accepted 19 June 2000

Abstract

Large-area scintillation counters used for triggering on muons at collider detectors can involve long transmission lengths which make the collection of an adequate amount of light difficult. This is a problem which aggravates as scintillator properties deteriorate with time and/or absorbed radiation. Inspired by the technique presently being applied to the construction of its new muon counters, a solution has been developed at CDF, which has permitted the collaboration to retain its older components for run II despite a dramatic deterioration in attenuation length in the course of run I. © 2000 Elsevier Science B.V. All rights reserved.

PACS: 29.40.Mc

Keywords: Scintillation detectors; Scintillator aging

1. Introduction

Wavelength-shifting-fiber (wls) readout of scintillator-based detectors is well established in calorimetry where its application is driven principally by the need for compactness, segmentation, and remoteness of the devices used for light sensors and amplifiers, e.g. photomultipliers (PMT). The same characteristics, also make it suitable for the readout of the large-area scintillation counters used for muon detection at collider detectors. In particular, its ability to collect light locally and its long attenuation length allows light generated far from the sensor to be collected more efficiently than by conventional light guide methods which rely on transmission through the scintillating material where attenuation lengths are relatively smaller. This can allow for coverage of larger areas and might even allow one to relax demands on the

☆Partially supported by Fermilab.

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PII: S0168-9002(00)00640-9

transmission properties of the scintillator. A priori choice of lower-grade scintillator becomes an option and doping to enhance brightness at the expense of transmission can be considered. Furthermore, because deterioration of scintillator transmission is one of the first consequences of aging, one can expect a better tolerance to aging, provided the wls fiber is less susceptible, which is certainly the case for radiation-related aging.

In this paper, we report on the application of wls fiber to the recovery of already deteriorated large-area muon counters at the Collider Detector Facility (CDF) at Fermilab. The work is in progress and results given here are preliminary .

2. Deterioration of CDF muon upgrade counters

Muon detectors at CDF are a combination of drift chamber stacks and scintillation counters [1,2]. The functions of the counters are to reduce background and/or "time stamp" track segments (referred to as *stubs*) in the corresponding drift chambers. This latter function will become important in the forthcoming run when bunch spacings will be reduced to as little as 132 ns. In that case, when chamber drift times would be as much as 10 times longer than the bunch spacing, the counters will be able to identify the bunch crossing corresponding to any stub at level 1 of the hardware trigger.

For the forthcoming run II, muon detector coverage will extend over most of the solid angle between a pseudorapidity η of 0 and 1.5. However, a large fraction of the solid angle in the range $0 \leq \eta \leq 1.0$ was already covered by scintillation counters[1] during run I (i.e. since 1992) and a significant deterioration in their efficiency was observed in the course of the run. This efficiency was measured for counters in the central region (designated CSP counters) using muons from reconstructed $Z \rightarrow \mu\mu$ events and found to be about 92% at the end of run 1. The corresponding efficiency for counters spanning $1.0 \leq \eta \leq 1.2$ (designated CSX counters) was measured using $J/\psi \rightarrow \mu\mu$ events and found to be about 82%.

The ensuing investigation led to the discovery that the scintillator had deteriorated to the degree that, when exposed to daylight, the light emitted by the scintillator was shifted visibly into the green, and measurements revealed that the transmission had indeed decreased by 1–2% between 400 and 500 nm where most of the scintillator emission occurs.

For a quantitative evaluation of the effects of this deterioration, counter outputs were calibrated by "photon counting" (see e.g. Ref. [3]). This was done by exposing them to short low-level light (~ 1 photoelectron at the PMT photocathode) pulses generated either by a pulsed U/V laser pulses or by a fast LED and identifying the single-photon peak. The average absolute light generated by a cosmic muon at the end of a CSP (see Fig. 2) farthest (i.e. 320 cm) from the PMT was found to be 4 photoelectrons. In Fig. 1 the absolute output of a typical CSP is compared with that from a counter (T32) made of identical (NE114) but undeteriorated scintillator and with that of a new polystyrene-based scintillator[2]. On the basis of this comparison, the rates of deterioration, at the points closest and farthest from the PMT photocathode were estimated to be 15 and 30% per year, respectively. From this, we concluded that both the brightness and the attenuation length of the scintillator had deteriorated, half of the light originating from the far end being lost because of deteriorating transparency.

This deterioration is not related to radiation because spare counters, which had never been exposed to radiation, manifested the same characteristics. Furthermore, a few test counters made from identical material, but from another batch, which were also used during the same period (Run I), manifested no such effects. Measurements of transparency for different thicknesses indicate that it is a bulk effect, rather than a surface effect. It is likely that the deterioration is due to poor de-oxygenation of the scintillator material during production.

Nevertheless, the effects are similar to those due to radiation damage and the method described in the following section for recovering some of the light lost might be applied generally.

[1] The PVT-based scintillator (NE114) was produced by Nuclear Enterprises Ltd.

[2] Produced by Monocrystall SA, Kharkov, Ukraine.

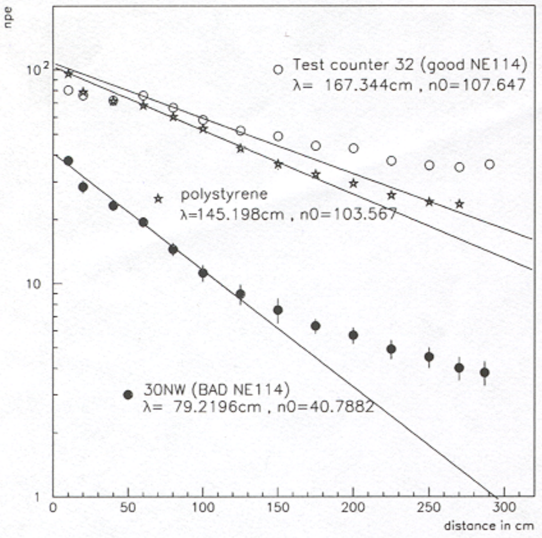

Fig. 1. Absolute light yield (in photoelectrons) as a function of distance from the photocathode. A typical CSP counter 30 NW is compared with a similar, undeteriorated counter (test counter 32) and with a new counter, constructed from polystyrene-based scintillator. Simple exponentials $\exp(x/\lambda)$, fitted to the data between 50 and 150 cm, are used to extrapolate to zero (x_0).

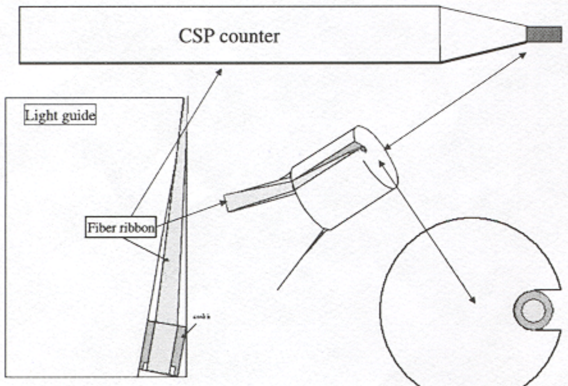

Fig. 2. Schematic illustration of how 20-fiber wls ribbons were glued to one side of the counter and routed to the PMT photocathode.

3. Refurbishing the aging counters

All counters constructed since the end of Run I [4] rely exclusively on wls fiber readout. The feasibility of this method of light extraction had therefore been established and it suggested a way of recovering sufficient light from the degraded counters to render them useful. By glueing a ribbon of wls fiber to the long side of the counters (see Fig. 2), one can collect light locally and since it is conveyed to the PMT through the fiber, it is not susceptible to the degradation in the scintillator attenuation length.

Preliminary tests with separate PMTs indicated that a muon passing through the far end of the counter would generate about 10 photoelectrons at the PMT photocathode. This is sufficient for $\geq 99\%$ efficiency. However, by routing the fiber to the same PMT which views the light component transmitted through the scintillator, we were able to both increase the total light output and use the original PMTs. The method for doing so is illustrated in Fig. 2 It involves routing the fiber through a groove machined in the light guide to the PMT photocathode. The low level of destruction involved has little effect on the light transmitted through the light guide, so that the total is the sum of the original light and the new component from the fiber ribbon.

Given that the scintillator is 2 cm thick, each wls ribbon comprised one layer of 20 fibers, each 1 mm in diameter. Double-cladded, Y11 (250 ppm) fibers produced by Kuraray[3] were used for most of the counts and only the results obtained with these fibers are reported here. Similar fibers produced by Pol.hi.tec.[4] were used for $\sim \frac{1}{6}$ of the counters with less satisfactory results. In order to augment the fraction of light generated by the fiber, which eventually reaches the PMT photocathode, the far ends of the fibers were polished and "mirrored" by evaporating an aluminium film on the polished ends. Reflective coefficients of about 80% are obtained in this way. A very useful by-product of this technique is that, although the total light collected decreases with distance from the photocathode of the PMT, the *amplitude* of the pulse eventually reaching the discriminator in the DAQ chain is almost constant. This is because the time separation between the direct and reflected light components decreases with increasing distance, so that they merge

[3] Kuraray CO., LTD., Tokyo. Japan.
[4] Pol.hi.tec s.r.l., Carsoli, AQ, Italy.

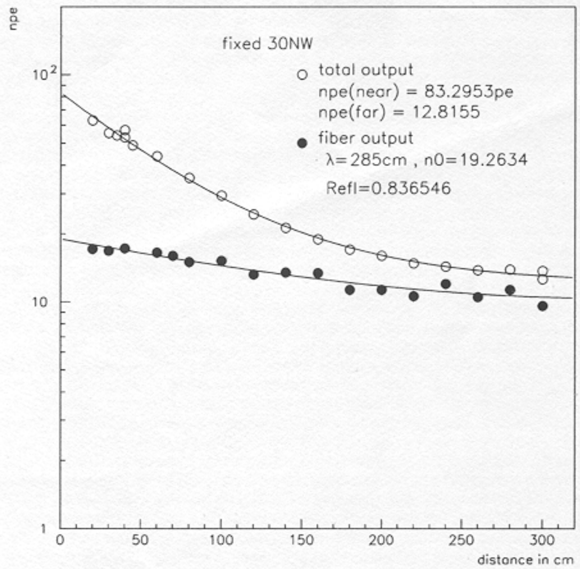

Fig. 3. Absolute light yield (in photoelectrons) as a function of distance from the photocathode (in cm). The total light output of the counter is compared with that of the fiber ribbon alone (fiber output). Functions used to fit the data a rediscussed in the text.

progressively and increase the amplitude. In effect, for muons traversing the counter near the PMT photocathode, only the direct light component triggers the discriminator, while for muons traversing at the far end, it is the combination of direct and reflected components which does so.

Results obtained with a typical counter are shown in Fig. 3. The "total output" represents the light reaching the PMT photocathode from both the light guide and the wls fiber, and the sum of two Gaussians that is fitted to it, is used only to extrapolate npe to the two ends of the counter. The "fiber output" represents the output of only the fiber ribbon and it is fitted with the following function: npe $= n_0(\exp(-x/\lambda) + R\exp((2l - x)/\lambda))$, where R is the reflection coefficient, l is the fiber length (370 cm), and λ is the fiber attenuation length which was measured separately and is kept fixed (285 cm). Parameters extracted are the fiber output at the PMT photocathode (n_0) and the reflection coefficient R of the fiber mirror.

At the time of this report, about $\frac{2}{3}$ of the counters have been repaired and the average light output from the far end of the refurbished CSPs is 16 photoelectrons (as opposed to 4 before refurbishing). This is more than adequate for full muon detection efficiency over the whole counter surface. If the rate of deterioration remains as estimated above, CDF will be able to take data with these counters at full efficiency until the end of the forthcoming run.

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